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FROST INVESTIGATION

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Summary.—This investigation is concerned with the incidence and severity of air frosts in the fruit-growing areas in the Fenland district and in the Lower Severn basin. The period covers the months of April and May for the years 1921–50 and standard observations of screen temperature are used. An attempt is made to consider both radiation and wind frosts, and account is also taken of the direction and speed of the wind recorded during both types of frost. A formula is obtained for the frost frequency over flat clay country.

Definitions.—A screen frost is said to occur when the minimum thermometer in a Stevenson screen is reported as 32°F. or less, that is, its reading is less than 32·5°F.

Screen frosts are divided into two types: radiation frosts and wind frosts. Radiation frosts occur on clear nights with little or no wind, the air temperature generally increasing with increasing height above the ground. Wind frosts occur at any time of the day or night, whatever the state of the sky, with a definite wind which brings the air from cold regions. On some occasions a wind frost may be intensified by radiation and the two types of frost occur simultaneously.

The surface wind is the wind at 33 ft. above the ground, and is estimated or measured by anemometers. The wind actually on the surface of the ground is usually considerably less.

A wind frost is said to occur when the surface wind at the time of the minimum temperature is more than 7·5 m.p.h., the value corresponding to the boundary between force 2 and force 3 on the Beaufort scale. A radiation frost is said to occur when the wind is less than this value.

When the air on the slope of a hill is cooled by radiation it tends to flow down hill as a katabatic wind, the direction of flow being dictated by the local orographic features. Local winds are thus sometimes reinforced by katabatic winds. Such flows of air lead to the accumulation of cold air and the formation of frost hollows.

Data.—The stations at which the observations* were made are shown in Fig. 1 which also shows the physical features of the two areas considered. Temperature was measured by alcohol minimum thermometers exposed in a

*To obtain a long period of observations for the Thetford area the data from two nearby stations, Santon Downham and Lynford Hall, were combined but wind roses were not drawn. Frequencies were also computed for each station separately and wind roses drawn.

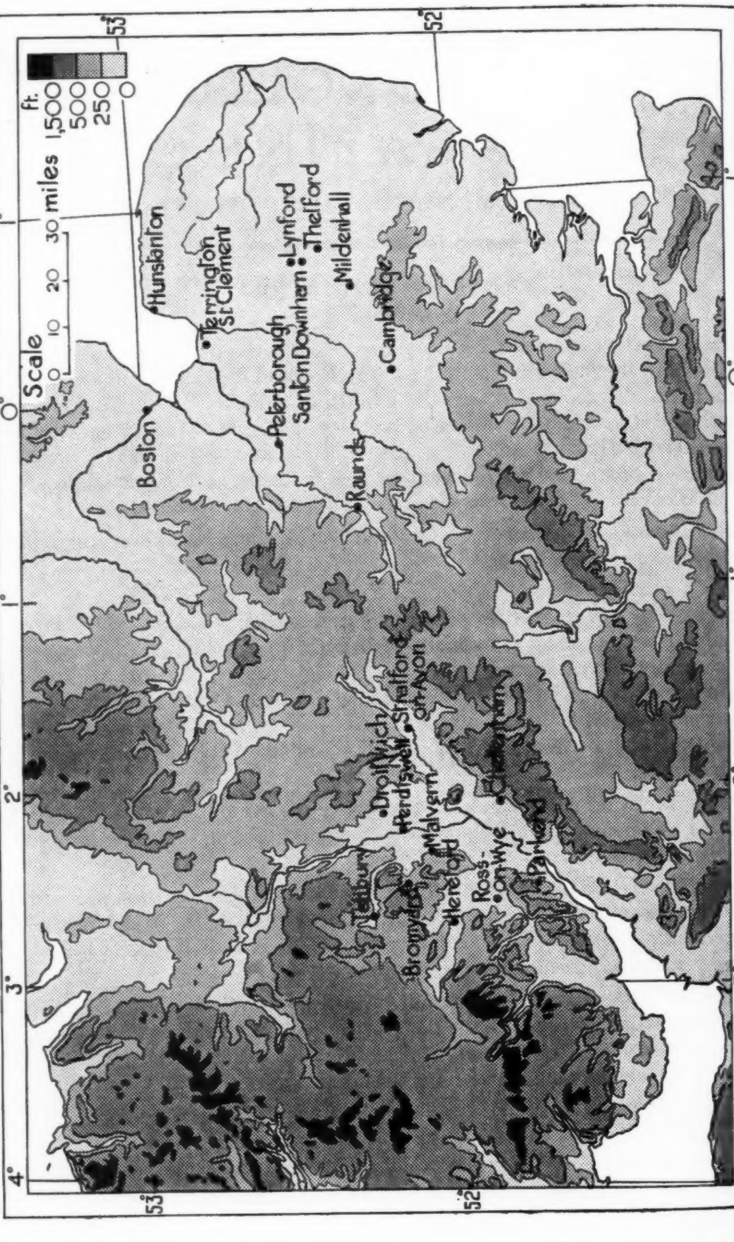


FIG. 1—MAP SHOWING THE FENLAND AND LOWER SEVERN AREAS

standard screen; the winds were mainly estimated, but in a few cases were measured by anemometer.

The standard period for the investigation was 1921–50, but the whole of this period was not available at all the stations. Table I shows the period available for each station.

TABLE I—PERIODS USED FOR TEMPERATURE AND WIND

	Period	No. of years		Period	No. of years
Raunds	1921–23, 1925–34, 1942–50	22	Cheltenham	1921–50	30
Peterborough	1940–46	7	Hereford	1921–50*	30
Cambridge	1921–50	30	Ross-on-Wye	1921–50	30
Mildenhall	1935–50	16	Malvern	1921–46, 1948–50	29
Boston	1938–41, 1943–50	12	Perdiswell	1926–50	25
Terrington St. Clement	1935–46	12	Bromyard	1921–42	22
Hunstanton	1924–50	27	Parkend	1932–50	19
Lynford	1933–42, 1949–50	12	Stratford-on-Avon	1933–38, 1941–50	16
Santon Downham	1944–48	5	Droitwich	1939–50	12
Thetford, (Lynford and Santon Downham)	1933–42, 1944–50	17	Tenbury	1921–22, 1924–28†	7

*Wind data available only from 1925 to 1950
†Wind data available only for 1921, 1922, and 1928

Relation between screen temperature and frost damage to fruit trees.—In a strong surface inversion, the screen temperature at 4 ft. may be considerably lower than the temperature at tree height. Furthermore the temperature inside the perimeter of the tree may be higher than the temperature on the outside of the tree at the same height because of the blanketing effect of the foliage. The temperature of an exposed bud is not necessarily that of the surrounding air. The critical temperature which causes damage is different for different varieties and for different stages of growth. Because of these complications it is difficult to select a fixed standard of reference in terms of screen minima, and to overcome this difficulty frost frequencies have been calculated with reference to a succession of screen threshold temperatures, namely 32°, 30°, 28° etc.

Effect of the time of observation.—The minimum temperatures considered were observed at times varying between 0600 and 0900 G.M.T. Those observations taken at the earlier hours of 0600 and 0700 were for a period of 12 hr. only. There is thus little chance of the minimum of one night being recorded as two frosts on successive nights, and therefore no correction has been made for the time of observation of temperature.

Wind was not recorded at the stations at the time of occurrence of the minimum temperature, so that to assess the number of wind frosts it had to be assumed that minimum temperature occurred at 0500 in April and 0400 in May. Given a wind at times between 0600 and 0900 the wind at 0400 or 0500 had then to be computed. Use was made of the normal rate of increase of light surface winds at Kew, and factors were determined which gave the proportion of the number of force 3 winds measured at 0600–0900 which were to be considered as force 2 winds at 0400 or 0500. These factors are given in Table II.

TABLE II—CONVERSION FACTORS (WIND)

	Time of observed wind			
	0600	0700	0800	0900
April	0·26	0·22	0·46	0·70
May	0·12	0·30	0·52	0·68

For example, if 10 frosts were recorded in May at 0700 with a force 3 wind, then 0·30 × 10 or 3 of these were regarded as occurring with a force 2 wind at the time of minimum temperature and were thus classified as radiation frosts and not wind frosts.

Effect of the period of observation.—The standard period was 1921–50, but full sets of records were not available for all stations and a system of qualitative weighting was devised with reference to the standard monthly averages for the 1881–1915 period (the "normal"). This is shown in Table III.

TABLE III—RELATION OF PERIOD AVAILABLE TO STANDARD PERIOD

	Period	APRIL Difference from normal	APRIL Effect on frost frequency*	MAY Difference from normal	MAY Effect on frost frequency*
		°F.		°F.	
Cambridge	1921–50	+1·1	=	+0·13	=
Raunds	1921–23, 1925–34, 1942–50	+1·55	=	+0·41	=
Peterborough	1940–46	+0·41	+	0·0	=
Mildenhall	1935–50	+1·8	−	−0·19	=
Lynford	1933–42, 1949–50	+0·83	=	−0·75	+
Boston	1938–41, 1943–50	+2·4	−	+0·08	=
Terrington St. Clement	1935–46	+1·6	−	−0·4	+
Hunstanton	1924–50	+1·3	=	+0·04	=
Standard period, 1921–50		+1·1		+0·13	

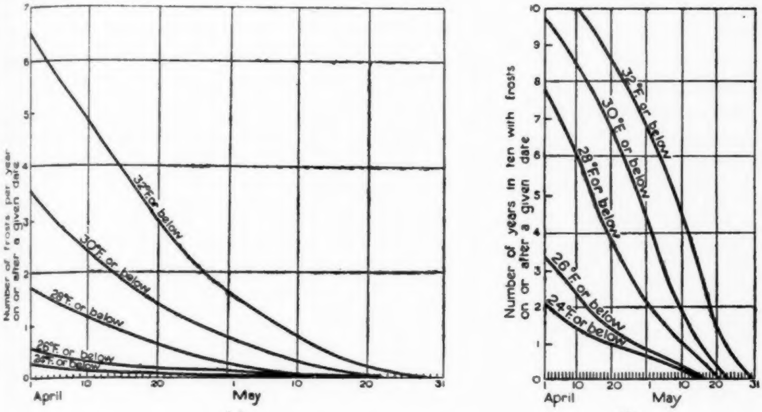
* = Frequency probably close to that for the standard period.
+ Frequency probably higher than that for the standard period.
− Frequency probably lower than that for the standard period.

Orography.—The more regular features of the Fenland area enabled a more detailed analysis to be made of the frost data than did the valleys and neighbouring hills of the Lower Severn area. The land in the east is mainly flat and all sites are below 200 ft. Such a uniformity makes comparison between sites possible, but with valley or hill sites marked differences exist which cannot be treated in a general manner.

Soil.—A simple classification of the soils at the various sites is given in Table IV.

TABLE IV—TYPES OF SOIL

Fenland area Station	Fenland area Soil	Lower Severn area Station	Lower Severn area Soil
Raunds	Clay	Cheltenham	Sand
Peterborough	Mainly clay	Hereford	Clay
Cambridge	Chalk and sand	Ross-on-Wye	Sandstone
Mildenhall	Mainly sand	Malvern	Variable
Lynford	Sand	Perdiswell	Loam
Santon Downham	Sand	Bromyard	Sandstone
Thetford	Sand	Parkend	Loam
Boston	Alluvial loam	Stratford-on-Avon	Clay
Terrington		Droitwich	Clay
St. Clements	Silt/Loam	Tenbury	Red clay and marl
Hunstanton	Sand/Chalk		



(a) (b)

FIG. 2—ACCUMULATIVE FROST FREQUENCIES AT CAMBRIDGE

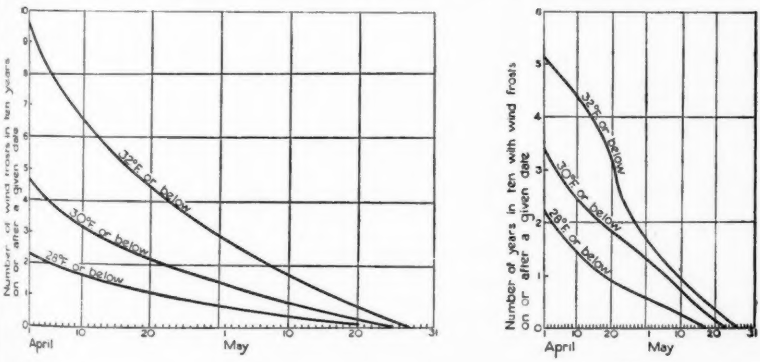
Calculation and representation of frost frequencies.—The average total number of frosts occurring on or after a given date was determined, and was called the "accumulative frost frequency". This was done for the frost "threshold values" of 32°, 30°, 28°, etc. The extracted figures were plotted in the form of a graph against a time base and the curves smoothed, Fig. 2(*a*).

Another set of curves was obtained by noting the date in each year of the latest frost of given severity; then, for each date of the period April 1–May 31, the average number of years in ten with such a frost on or after this date was found, Fig. 2(*b*).

These two sets of graphs were also constructed for wind frosts alone (Fig. 3).

Wind roses were drawn for frosts of varying severity, showing the frequency of wind direction during (i) wind frosts, and (ii) radiation frosts.

Frost frequency and soil type.—The relationship between frost frequency and soil type depends a great deal on the water-holding properties of the soil. Over clay, for example at Peterborough, there was a marked decrease in frost



(a) (b)

FIG. 3—ACCUMULATIVE WIND FROST FREQUENCIES AT CAMBRIDGE

frequency in the slight-to-medium frost range. Over sand, as at Thetford, the frost frequency was almost a linear function of the threshold temperature. In the west the three stations with clay soil, Droitwich, Stratford-on-Avon and Hereford, showed a greater difference between the frequencies of 32° and below and the frequencies of 30° and below than those between 30° and below and 28° and below. Stations on loam, Perdiswell and Parkend, showed a reverse effect in that the greater difference occurred between the frequencies of 30° and below and the frequencies of 28° and below.

Lower Severn data.—No method of numerical combined analysis was found suitable for use with stations in the irregular terrain of the south-west Midlands. The data were, therefore, considered in a qualitative manner, and for each station the direction of probable katabatic flow was estimated. These estimates were compared with the frost wind roses. At four of the stations, Perdiswell, Bromyard, Parkend and Statford-on-Avon, the predominating winds of the frost wind rose were from the direction of the estimated katabatic flow. These stations were those with the highest frost frequencies, with the sole exception of Droitwich which appeared to have no marked katabatic winds and which probably owed its high frost frequency to its distance inland. The stations with the lower frost frequencies had wind roses dissimilar to the expected katabatic winds, which suggests that they have good cold-air drainage.

The data examined, therefore, confirmed the generally held view that in undulating or hilly country the question of air drainage is of paramount importance in determining frost frequency.

Frost frequency and height.—With the exception of Malvern, Table V shows that the most frosty stations are those below 200 ft. or above 320 ft. The evidence of the wind-frost data is by no means clear-cut. The average height of the stations with the highest wind-frost frequencies is 283 ft. and with the lowest frequencies 274 ft., while the average height of the remainder of the stations is 221 ft., from which no firm conclusions can be drawn.

TABLE V

	Height	Position in decreasing order of frost frequency		
		Total frost	Wind frost	Radiation frost
	ft.			
Perdiswell	94	4	6	3
Droitwich	106	1	4	1
Stratford-on-Avon	210	5	1	6
Cheltenham	214	9	10	9
Ross-on-Wye	226	8	8	8
Hereford	292	6	5	5
Tenbury	313	7	3	7
Parkend	325	2	2	4
Malvern	383	10	9	10
Bromyard	393	3	7	2

Wind and frost.—Many of the sites showed a distinct prevailing wind associated with frost, and some of them showed a prevailing wind direction for radiation frosts and another for wind frosts. These directions could usually be explained with reference to the local orography. In general, radiation frosts were more frequent than wind frosts and gave rise to lower temperatures more frequently. Also the lowest temperature at a particular site usually occurred in the lower wind-force range.

The wind roses are not reproduced here but the frequencies of frosts of 28° or below for ranges of wind force 0–2 and $\geqslant 3$ for the eight main directions are given in Tables VI and VII.

A formula for the observed frequency of frost.—In selecting a site for fruit, the grower wishes to know the chances of frost after a given date, and with the development of frost-prevention methods he also wishes to know the actual frequency of frosts to assess how many times he needs to use the methods at his disposal.

Frost incidence is essentially local in character and a complete simple formulated solution is not possible. In an attempt to discover a formula, the area with least topographical variations, the Fenland area, was selected for analysis. The frost frequency was linked with the date, the distance from the sea, the severity of the frost (threshold temperature) and the type of soil. The formula was of the form

$$\log F = A + BT + Cx + Dt$$

where F is the average number of frosts after a given date, T is the threshold temperature, x is the distance from the sea in miles, t is the date in weeks after April 1, and A, B, C, and D are constants, A being a soil constant.

TABLE VI—FROST FREQUENCY AND WIND IN THE FENLAND AREA

Temperature $\leqslant$28°F.

	Month	Wind force	Calm, or light variable	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Total
			frequency per ten years									
Raunds ...	April	0–2	1·4	0·5	1·2	1·2	0·7	0·7	1·0	1·4	1·0	9·1
		$\geqslant$3	0·0	1·2	0·8	0·2	0·5	0·0	0·0	0·0	0·7	3·4
	May	0–2	0·5	0·7	1·4	0·3	0·3	0·0	0·0	0·2	1·0	4·3
		$\geqslant$3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·3	0·3	0·5
Peterborough ...	April	0–2	1·4	0·0	2·1	0·7	0·0	0·0	0·0	0·0	0·0	4·2
		$\geqslant$3	0·0	0·0	0·0	0·0	0·0	0·0	0·7	0·7	0·0	1·4
	May	0–2	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
		$\geqslant$3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
Cambridge ...	April	0–2	0·7	1·7	2·0	1·3	1·7	0·7	2·2	1·8	1·3	13·3
		$\geqslant$3	0·0	0·0	0·3	0·0	0·0	0·0	0·7	0·0	0·0	1·0
	May	0–2	0·0	0·5	1·0	0·7	0·3	0·0	0·0	0·0	0·2	2·7
		$\geqslant$3	0·0	0·0	0·0	0·0	0·0	0·3	0·0	0·0	0·0	0·3
Mildenhall ...	April	0–2	1·9	2·8	1·5	1·2	0·6	1·2	1·2	2·5	0·6	13·5
		$\geqslant$3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
	May	0–2	0·6	1·2	0·0	0·0	0·0	0·0	0·0	0·3	1·5	3·6
		$\geqslant$3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·3	0·3	0·6
Boston	April	0–2	0·9	0·9	0·0	0·9	0·0	0·0	0·0	0·9	0·9	4·4
		$\geqslant$3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
	May	0–2	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·9	0·9
		$\geqslant$3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·9	0·9
Terrington St. Clement	April	0–2	0·0	0·9	1·7	0·0	0·0	0·0	0·0	0·0	0·9	3·4
		$\geqslant$3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
	May	0–2	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·9	0·0	0·9
		$\geqslant$3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
Hunstanton ...	April	0–2	0·4	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·4
		$\geqslant$3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
	May	0–2	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
		$\geqslant$3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
Lynford ...	April	0–2	0·0	5·0	10·0	3·3	1·7	2·5	4·2	3·3	3·3	33·4
		$\geqslant$3	0·0	1·7	5·0	0·9	0·9	0·0	0·9	1·7	0·9	11·9
	May	0–2	0·0	1·7	5·0	1·7	0·9	1·7	0·0	0·9	0·9	12·7
		$\geqslant$3	0·0	0·9	0·0	0·0	0·0	0·0	0·9	1·7	0·9	4·3
Santon Downham	April	0–2	4·0	2·0	10·0	2·0	4·0	2·0	14·0	0·0	6·0	44·0
		$\geqslant$3	0·0	0·0	2·0	0·0	0·0	0·0	0·0	0·0	2·0	4·0
	May	0–2	0·0	2·0	4·0	0·0	0·0	0·0	6·0	0·0	2·0	14·0
		$\geqslant$3	0·0	0·0	2·0	0·0	0·0	0·0	0·0	0·0	2·0	4·0

TABLE VII—FROST FREQUENCY AND WIND IN THE LOWER SEVERN AREA

Temperature $<28°$F.

	Month	Wind force	Calm, or light variable	N.	NE.	E.	SE.	S.	SW.	W	NW.	Total
			frequency per ten years									
Cheltenham ...	April	0–2	0·3	0·5	0·2	0·3	0·0	0·0	0·2	0·8	0·3	2·7
		⩾3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
	May	0–2	0·0	0·3	0·0	0·0	0·2	0·2	0·0	0·0	0·0	0·7
		⩾3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
Hereford ...	April	0–2	0·8	1·8	2·3	1·7	0·6	0·4	0·0	0·0	1·4	9·0
		⩾3	0·0	0·4	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·4
	May	0–2	0·0	0·2	0·4	0·0	0·0	0·0	0·4	0·0	0·6	1·6
		⩾3	0·0	0·4	0·0	0·0	0·0	0·0	0·0	0·4	0·0	0·8
Ross-on-Wye ...	April	0–2	1·7	0·7	0·2	0·2	0·0	0·5	1·0	0·5	0·7	5·3
		⩾3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
	May	0–2	0·0	0·0	0·0	0·0	0·0	0·2	0·5	0·0	0·0	0·7
		⩾3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
Malvern ...	April	0–2	0·3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·3
		⩾3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
	May	0–2	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
		⩾3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
Perdiswell ...	April	0–2	0·8	2·8	2·4	0·6	1·0	0·8	2·4	1·2	2·4	14·4
		⩾3	0·0	0·0	0·0	0·0	0·0	0·0	0·4	0·0	0·4	0·8
	May	0–2	1·2	1·6	0·0	0·0	0·0	0·4	0·4	0·8	0·4	4·8
		⩾3	0·0	0·0	0·0	0·0	0·4	0·0	0·0	0·0	0·0	0·4
Bromyard ...	April	0–2	1·4	2·7	1·8	0·5	2·3	1·8	0·9	0·9	2·7	15·0
		⩾3	0·0	0·0	0·5	0·5	0·0	0·0	0·0	0·0	0·5	1·5
	May	0–2	0·0	0·0	0·0	0·5	0·5	0·0	0·0	0·5	0·5	2·0
		⩾3	0·0	0·0	0·0	0·5	0·0	0·0	0·0	0·0	0·0	0·5
Parkend ...	April	0–2	0·0	1·1	2·6	0·0	0·5	1·6	1·9	0·7	0·5	8·9
		⩾3	0·0	0·0	0·5	0·0	0·0	0·0	0·5	0·0	0·5	1·5
	May	0–2	0·0	0·0	0·5	0·0	0·0	0·0	0·5	1·1	0·5	2·6
		⩾3	0·0	0·0	0·5	0·0	0·0	0·5	0·5	0·0	1·1	2·6
Stratford-on-Avon	April	0–2	0·6	0·9	0·3	0·0	0·6	1·2	0·6	3·1	1·2	8·3
		⩾3	0·0	0·6	0·0	0·6	0·0	0·0	0·0	0·6	0·0	1·8
	May	0–2	0·6	0·0	1·2	1·2	0·0	0·3	0·9	1·2	0·0	5·4
		⩾3	0·0	0·0	0·6	0·6	0·0	0·3	0·3	0·0	0·0	1·8
Droitwich ...	April	0–2	2·5	0·0	2·5	0·0	0·0	2·5	2·5	0·9	4·2	15·1
		⩾3	0·0	0·0	0·9	0·0	0·9	0·0	0·9	0·0	0·0	2·7
	May	0–2	0.9	0·0	5·0	0·0	1·7	0·9	3·3	1·7	1·7	15·1
		⩾3	0·0	0·0	0·0	0·0	0·0	0·0	0·9	0·0	0·9	1·7
Tenbury ...	April	0–2	0·0	0·0	5·0	5·0	3·3	0·0	0·0	3·3	13·3	30·0
		⩾3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
	May	0–2	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
		⩾3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0

Sufficient data were available to obtain the complete formula for clay soil. Over sand, with the greater range of frequency of frosts and the more linear relation of frequency with intensity the formula similarly obtained would probably hold true to an even better extent, but an inadequate range of observations made its computation impossible.

Analysis of frequency.—The frequency curves in the Fenland area were found to satisfy an equation of the form:—

$$\log F = a - bt \qquad (F > 1)$$

This equation's closeness of fit with the observed values was statistically acceptable. Values of the constants, a and b, for the various stations are given in Table VIII.

In Table VIII the value of a decreases at the rate of 0·30 (approx.) per 2 degrees fall in threshold temperature. We can therefore write:—

$$a = c + dT$$

where T is the threshold temperature and c and d are constants with respect to t and T. The value of the constant d for Raunds and Peterborough, both on

TABLE VIII—COEFFICIENTS IN THE FROST FREQUENCY FORMULA

	Distance from sea	Threshold temperature 32°F.		Threshold temperature 30°F.		Threshold temperature 28°F.	
	x	a	b	a	b	a	b
	miles						
TOTAL FROST FREQUENCY							
Raunds	45	0·88	0·15	0·52	0·14	0·22	0·12
Peterborough	25	0·59	0·15	0·23	0·15	...	...
Cambridge	42	0·85	0·15	0·57	0·17	0·26	0·16
Mildenhall	30	0·88	0·14	0·64	0·13	0·30	0·14
Lynford	25	1·11	0·16	0·96	0·16	0·86	0·15
Boston	3	0·70	0·15	0·39	0·15	...	...
Terrington St. Clements	3	0·70	0·12	0·33	0·13	...	...
Hunstanton	0	−0·28	0·17	...	...	...	...
WIND-FROST FREQUENCY							
Raunds	45	0·27	0·14	−0·01	0·14	...	...
Peterborough	25	−0·09	0·17	...	...	...	...
Cambridge	42	0·00	0·14	−0·33	0·12	−0·63	0·12

clay soils, was found to be 0·18. The relationship between the values of c and the distance x from the sea in Table V was found to be approximately linear, so that

$$c = A + 0{\cdot}015x$$

where A is a constant depending on the type of soil, and is, for example, the same for Raunds and Peterborough, namely $-5{\cdot}55$. Therefore the formula for the total accumulative frost frequency for sites over flat clay soil can be written

$$\text{Log}\, F = -5{\cdot}55 + 0{\cdot}18T + 0{\cdot}015x - 0{\cdot}15t.$$

Comparison between east and west.—If the ten stations in the west and the eight stations in the east are arranged in descending order of frost frequency the following order is obtained:—

1	Lynford/Santon Downham	(E.)	10	Hereford	(W.)
2	Droitwich	(W.)	11	Tenbury	(W.)
3	Parkend	(W.)	12	Boston	(E.)
4	Bromyard	(W.)	13	Terrington	(E.)
5	Perdiswell	(W.)	14	Peterborough	(E.)
6	Stratford-on-Avon	(W.)	15	Ross-on-Wye	(W.)
7	Mildenhall	(E.)	16	Cheltenham	(W.)
8	Cambridge	(E.)	17	Malvern	(W.)
9	Raunds	(E.)	18	Hunstanton	(E.)

In general, therefore, the western sites are more frosty than the eastern ones, but when wind frosts alone are taken into consideration the eastern sites are frostier.

Mean minimum temperature and frost frequency.—The mean minimum temperature for each of the months April and May for each station was correlated with the average number of frosts of temperature $\leqslant 28°$ during each of these months. The values of the correlation coefficients were found to be $-0{\cdot}94$ (April) and $-0{\cdot}82$ (May). Thus the mean monthly minimum temperature appears to be a useful indicator of the mean monthly frost frequency (threshold temperature 28°).

Conclusions.—

(*a*) The factors to be taken into consideration in regard to frost frequencies are the date, the intensity, the distance from the sea, the soil and the orographical nature of the country.

(*b*) In hilly country the orographical features are the most important; the frequencies obtained in this investigation can apply only to the sites where the measurements were made.

(*c*) Frosts are more frequent over sandy soils than over clay.

(*d*) The frostiest stations in this investigation are situated in the hilly country of the west with the exception of Thetford. Radiation frosts are generally more common than wind frosts and give rise to lower temperatures. Wind frosts are more common in the flat country of the east.

(*e*) The mean minimum temperature (April or May) is a useful indicator of the frost frequency of a station (threshold temperature 28°).

(*f*) There is no clear-cut relationship between frost frequency and height above sea level.

(*g*) At many stations there was a distinct prevailing wind on occasions of frost, and sometimes a second prevailing wind associated with wind frosts.

(*h*) The frequency of frosts over clay soils in East Anglia can be represented by a formula of the type

$$\log F = A + BT + Cx + Dt$$

where A, B, C, and D are constants and T, x and t are the threshold temperature, distance from the sea and time after April 1, respectively.

A similar formula could probably be extracted for sandy soils.

ELECTRONIC COMPUTING MACHINES AND METEOROLOGY

By J. S. SAWYER, M.A.

During the Second World War 1939–1945 a computing machine, the ENIAC, was completed in America, at Aberdeen, Maryland. It was of revolutionary design employing electronic methods, and it enabled numerical calculations to be performed a thousand times faster than was possible by methods which were available before the war. Further development of electronic computing machines has proceeded rapidly, and three machines have been built in this country for research purposes; at Cambridge, Manchester and at the National Physical Laboratory. These employ basically similar methods although they differ substantially in design; they are still in the experimental stage, but are already capable of undertaking calculations which were previously regarded as impracticable because of the enormous labour expended in manual methods.

It is not suprising that these developments in calculating methods should have stimulated meteorologists to consider whether the new machines can be used to advance the science of meteorology, and whether perhaps they may not ultimately have an application to forecasting. The subject has been discussed at a number of recent meetings and colloquia, and in order to appreciate the ideas which are being put forward it is necessary to recall something of the relevant background of meteorology and mathematics.

It was L. F. Richardson who, during the First World War 1914–1918, visualized the possibility of applying numerical methods to weather forecasting. His calculations in his book "Weather prediction by numerical process"[1] were a failure, whether from lack of initial observations or from incompleteness of knowledge of the atmospheric process we do not know, but his remarkable attempt demonstrated the possibilities and emphasized the difficulties—64,000 computers would be required to keep pace with the weather of the globe according to his estimation.

The new machines make it appear that perhaps L. F. Richardson's "forecast factory" was not so fantastic after all. Since 1945 J. G. Charney in America has given serious attention to the problem and his first calculations on the ENIAC are reported in a recent issue of *Tellus*[2]. Charney's approach differs considerably from that of Richardson. Richardson attempted to compute the future state of the atmosphere from an observed initial state, making very few assumptions about the possible types of motion which could occur in the atmosphere and being guided only by the observations made at his initial time. Charney on the other hand has endeavoured to simplify the problem by considering, not the atmosphere in all its complexity but a simplified "model" of the atmosphere which might be expected to behave according to more simple mathematical relations. For his calculations on ENIAC he considered only the flow of the atmosphere at 500 mb., and assumed that this would proceed as if the atmosphere were of uniform density (without temperature contrasts) and without friction (the barotropic model). Charney did not expect a perfect prediction on this basis—his model was only the first step in the development of a more realistic scheme.

For the purpose of discussing meteorological calculations it is not necessary to understand the inner workings of these remarkable computing machines. Suffice it to say that they operate by counting electronic pulses. EDSAC, the Cambridge machine, can perform an addition in about 1½ thousandths of a second and a multiplication in about 6 thousandths of a second. However, information can only be fed into the machine at the rate of 40 symbols per second, and information can only be read out from the machine at 15 symbols per second. Numbers can be represented in the internal store of a machine by a variety of devices, but only a limited set of numbers can be retained in the machine in this way. The operation of committing these numbers to paper takes far longer than many of the calculations themselves, and thus it is essential for efficient operation that as many relevant numbers as possible should be held within the machine. Otherwise the machine must wait while numbers are fed in or taken out and the advantage of its remarkable speed is lost. Various devices have been developed to extend the capacity of the machines for retaining the numbers within them, their so-called "memory", but it is a feature of problems of meteorological dynamics that many individual numbers are involved, several for every point of the chart, and meteorological problems may well tax the "memory" of even the most modern machines.

A computing machine, whether operated mechanically or electronically, can perform only the simple operations of arithmetic: addition, subtraction, multiplication and division. The numbers with which it operates and the order in which the operations are to be performed must first be decided by the mathematician and set out in a body of rules which the machine can follow.

These rules or instructions to the machine are known as the "programme", and with most of the electronic machines, these, as well as the numbers, have to be stored within the machine in order that it need not wait after performing one operation while instructions as to the next are fed into it.

The problem of applying electronic machines to meteorology therefore contains two important essential stages. First, the meteorological problem must be expressed as a set of mathematical equations, often partial differential equations, of which we require a solution. Secondly, the solution of these equations must be broken down into a series of arithmetical operations which are to be performed upon the initial observed values of the variables; this is the stage of "programming" for the machine.

It was against this background that a colloquium was held at Cambridge on September 6, 1951, on "Numerical methods in meteorology". Opening the discussion, Dr. R. S. Scorer stressed the possible application of electronic computing to meteorology other than the problem of forecasting. He mentioned the problem of recomputing the tephigram on a slightly different basis, the problems of the growth of raindrops and some problems on the dynamics of standing waves in the lee of obstacles. Later speakers, who included Dr. Charney, concentrated on the problem of the dynamics of the synoptic weather systems, an essential to the problem of forecasting. Mr. F. H. Bushby described some preliminary hand computations made at Dunstable which it was hoped would justify the study of a more complicated model than that adopted by Dr. Charney; Mr. Bushby's treatment makes some allowance for horizontal temperature differences, baroclinity. Dr. E. T. Eady described preliminary calculations at Imperial College, London.

The Meteorological Research Committee has shown its interest in the possibilities of electronic computing machines by including in its programme of investigations the "application of computing machinery to forecasting problems", and a member of the scientific staff of the Meteorological Office, Mr. Bushby, attended a recent course on the preparation of programmes for automatic digital computing machines.

Returning from this course in October 1951, Mr. Bushby opened a colloquium at the Central Forecasting Office, Dunstable, at which the possibilities of high-speed computation in meteorology were again discussed. During the discussion emphasis was placed on the probable value of numerical computations in improving our understanding of the dynamics of weather systems. There was a lively discussion of the merits of applying the first calculations to the behaviour of a textbook model cyclone rather than to the irregular disturbances of a real synoptic chart; nevertheless all were agreed that numerical methods had a more immediate application to dynamical research than to forecasting.

Enough has been written above to indicate that numerical meteorology is likely to become a subject of real interest. The number of workers on the subject is small at present, but there is real activity in a number of centres. The difficulties of the subject are considerable. Perhaps the most important is that we do not know if the equations widely used in meteorological dynamics do in fact adequately describe the motion of the atmosphere. Over periods exceeding 24 hours factors such as radiational heating and friction certainly enter, but these are usually neglected. The results of numerical integration over shorter periods will in fact be a crucial test of the theory.

A second difficulty is that little experience has so far been gained by the mathematicians in the integration on the new machines of the type of partial differential equation which is likely to arise in meteorological dynamics. New mathematical methods may need to be devised.

It is tempting to speculate on the future possibilities—perhaps to envisage revolutionary change in forecasting methods. However, there is much research and development to be done, and routine application of the methods to forecasting is therefore unlikely for many years to come. Nevertheless whether success or failure is the end of the attempts at numerical prediction, the experiments should improve our understanding of meteorological dynamics. The basic theory, which will be used in attempts at numerical prediction, is also the foundation of much besides in meteorology, so that if we only learn that the theoretical basis of computation is faulty, the effort will not have been in vain. However, there is reason to hope for better results; a satisfactory explanation of the development, movement and decay of weather systems may well be forthcoming.

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VAPOUR PRESSURE OVER THE SEA

By G. A. TUNNELL, B.Sc.

In an attempt to derive a simple method of estimating average vapour pressure over sea areas a number of interesting correlations were computed using data collected on the voyages of the *Carnegie*[1] during 1928–29 and the *Meteor*[2] during 1925–27.

The *Carnegie* sailed over the Atlantic Ocean between Iceland and about 10°N. and over the Pacific Ocean between the Aleutians and 40°S. The *Meteor* sailed between South America and Africa mainly on east-west and west-east courses ranging from 20°N. to 65°S. approximately. The *Meteor* made three observations a day (0700, 1400 and 2100 local time) while the *Carnegie* made daily observations at noon (G.M.T.).

The data have been classified according to wind force and the following linear equation fitted to each class for each ship,

$$e_h = ae_o + b\,\Delta T + c \qquad \ldots\ldots (1)$$

where e_h = vapour pressure in millimetres in the screen on the ship

e_o = saturation vapour pressure in millimetres at sea surface temperature

ΔT = temperature difference in degrees Centigrade between air and sea (positive if air temperature exceeds sea temperature)

a, b, c are coefficients derived from the data.

Table I gives the results of the analysis. Observations taken within 50 miles of land have been removed from the data. All the details of the correlations have been given so that the relationships between differences can be derived by anybody who is interested.

The coefficients of multiple correlations between e_h and the independent variables e_o and ΔT have been included to give a measure of the closeness of fit of equation (1). It is surprising how good this is and it emphasizes how

TABLE I—ANALYSIS OF VAPOUR PRESSURE AND TEMPERATURE AS OBSERVED OVER THE SEA ON THE VOYAGES OF THE *Carnegie* AND *Meteor*

Beaufort wind force	No. of obs.	Vapour pressure at screen level (e_h) Mean	S.D.*	Range	Saturation vapour pressure at sea temperature (e_0) Mean	S.D.*	Range	Difference between air and sea temperature (ΔT) Mean	S.D.*	Range	Correlation coefficients between e_h and e_0	e_h and ΔT	e_0 and ΔT	Coefficients in equation (1) a	b	c	R†
		millimetres			*millimetres*			°C.	°C.	°C.							
Observations on the *Carnegie* (screen height: 3·7 m. above sea level)																	
0, 1, 2	98	17·2	4·7	7·7 to 24·4	22·4	6·5	7·7 to 30·4	−0·4	1·1	−3·1 to +2·2	+0·94	−0·14	−0·32	+0·72	+0·74	+1·40	0·96
3, 4	209	16·4	4·6	7·3 to 24·4	21·0	6·6	7·6 to 30·8	−0·3	1·0	−4·6 to +2·4	+0·95	−0·08	−0·26	+0·70	+0·82	+1·92	0·97
5, 6	55	15·4	5·7	7·4 to 23·8	18·9	7·4	8·0 to 30·4	−0·2	1·2	−4·8 to +2·2	+0·95	−0·14	−0·38	+0·81	+1·25	+0·28	0·98
Observations on the *Meteor* (screen height: 9 m. above sea level)																	
0, 1, 2	120	13·8	5·7	3·6 to 24·4	19·0	7·4	5·0 to 31·7	−1·1	1·3	−5·8 to +2·6	+0·96	+0·08	−0·09	+0·75	+0·77	+0·35	0·98
3, 4	655	14·5	5·5	3·3 to 24·4	19·4	7·1	4·8 to 30·8	−0·6	1·1	−6·4 to +3·2	+0·95	−0·06	−0·24	+0·77	+0·89	+0·12	0·97
5, 6	332	11·6	5·1	3·7 to 23·8	15·4	7·0	4·9 to 30·4	−0·5	1·4	−6·0 to +2·5	+0·94	+0·03	−0·20	+0·72	+0·83	+0·95	0·97
>6	61	8·1	3·4	3·2 to 18·0	11·2	4·2	4·9 to 22·7	−1·7	2·6	−8·0 to +2·6	+0·80	+0·28	−0·25	+0·75	+0·67	+0·82	0·94

* Standard deviation. † R = multiple correlation coefficient

much the conditions at the surface of the sea control those several metres above.

The coefficient *a* does not vary much except in the case of the *Carnegie* where there are indications of a discontinuity between forces 3 and 4 and forces 5 and 6. The coefficient *b* increases with wind force in the *Carnegie* equations, while in the *Meteor* equations there is an increase and a decrease with wind force. The *Carnegie* data again give a discontinuity in *b* between forces 3 and 4 and forces 5 and 6. The values of *c* differ so completely that it is thought that they depend on individual peculiarities of each ship.

Although to some extent the data are biased (for example light winds are frequent in the tropics while strong winds are frequent in temperate regions), these results suggest that, with high-quality observations from ships, statistical methods could be used to investigate the general relationships between the meteorological elements of the atmosphere just above the sea.

These analyses have been carried out using individual observations but the relationships derived would give the most satisfactory results when applied to average values of e_0 and ΔT.

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METEOROLOGICAL OFFICE DISCUSSION

Forecasting winds at 30,000–40,000 ft. and above

The discussion on January 14, 1952, dealt with the forecasting of winds at 30,000–40,000 ft. and above. The opening speakers were Mr. R. Murray and Mr. C. S. Durst.

Mr. Murray was concerned with the value and limitations of the conventional method of representing the upper wind flow by constructing the contours of the isobaric surfaces at 300, 200 and 100 mb. and assuming the validity of the geostrophic approximation. The forecasting of the upper wind flow is reduced effectively to forecasting the behaviour of the contour patterns. It is not possible to lay down hard and fast rules for forecasting contour patterns. At the Central Forecasting Office the surface forecast chart (prebaratic) is prepared first, and the upper-level forecast charts (prontours) are constructed by the thickness method on the foundation of the prebaratic so as to ensure mutual consistency between surface and upper air patterns. This procedure does not imply that the prebaratic is drawn independently of the upper air wind and temperature field. The upper air situation is always studied carefully before the prebaratic is prepared. The long-wave pattern, regions of probable cyclonic and anticyclonic development as suggested by Sutcliffe's thermal vorticity theory, extrapolation, and empirical knowledge are some of the considerations which determine the prebaratic as well as the prontour picture.

However, the accuracy with which contour charts can be used in practice to forecast upper winds depends on several factors in addition to the accuracy with which the contour patterns can be forecast.

The apparent geostrophic departure on a set of working charts prepared at the Central Forecasting Office has been found to have a root-mean-square value of 20 kt. at 300 mb. and 18 kt. at 200 mb. These figures appear to place a limit to the accuracy with which working contour charts at 300 and 200 mb. can be used to represent the wind field, assuming the geostrophic approximation. These errors in terms of wind arise from (i) errors due to errors in contour-height observations, (ii) errors due to the measurement of geostrophic wind, (iii) errors due to the personal element in chart construction, (iv) wind errors, (v) small-scale wind fluctuations, and (vi) real geostrophic departures. An assessment of the magnitude of the individual types suggests that (i) and (vi) are most important and that (iv) and (v) are negligible.

In forecasts based on forecast contour charts (prontours) additional errors arise through incorrect forecasting of the contour patterns. If measured geostrophic winds from 24-hr. prontours are compared with the observed winds the vector errors may readily be obtained. For the region of the British Isles a test has given values of 33 kt. at 300 mb. and 25 kt. at 200 mb. for the root-mean-square 24-hr. forecast errors associated with prontour charts prepared at the Central Forecasting Office. Now the root-mean-square apparent geostrophic departure on the working contour charts is about 20 kt. at 300 mb. and 18 kt. at 200 mb. Subtracting these inherent errors in technique from the total forecast errors, we obtain 26 kt. at 300 mb. and 17 kt. at 200 mb. for the root-mean-square errors associated with erroneous forecasting of the contour patterns themselves.

The percentage of the 24-hr. wind variance successfully forecast is 75 per cent. at 300 mb. but only about 40 per cent. at 200 mb. However, if the errors in forecasting the contour gradients (26 kt. at 300 mb. and 17 kt. at 200 mb.) are regarded as the real forecasting errors, then the percentage success improves to 83 per cent. at 300 mb. and 77 per cent. at 200 mb.

Point forecasts are the most difficult to make. For aviation purposes forecasts of the mean wind or of the equivalent headwind over a route are of more practical importance; for such purposes the vector errors of mean wind are substantially less. For instance, for a 1,200-mile route a test has shown that the root-mean-square vector errors in 24-hr. forecasts of mean wind are about 22 kt. at 300 mb. and 17 kt. at 200 mb. (these errors include both the inherent errors in technique and the real errors associated with forecasting the contour gradients).

Since the spring of 1951 100-mb. charts have been drawn at Dunstable. At this high level the wind and temperature observations are less numerous; also the temperature observations are less accurate than at lower levels. Thus really dependable contour charts are very difficult to draw at 100 mb., although the broad, long-wave patterns can be shown clearly.

High-level wind forecasting by means of contour charts for periods up to 24 hours, although not unsatisfactory for some purposes, certainly cannot be said to have reached the optimum standard of accuracy. The main improvement is likely to come from improved methods of forecasting the contour patterns, but at 200 mb. and above there is room for considerable improvement in the quality and number of the observations.

Mr. Durst stated that what he was going to say was intended to be from a practical angle. For research work contours were essential even though they

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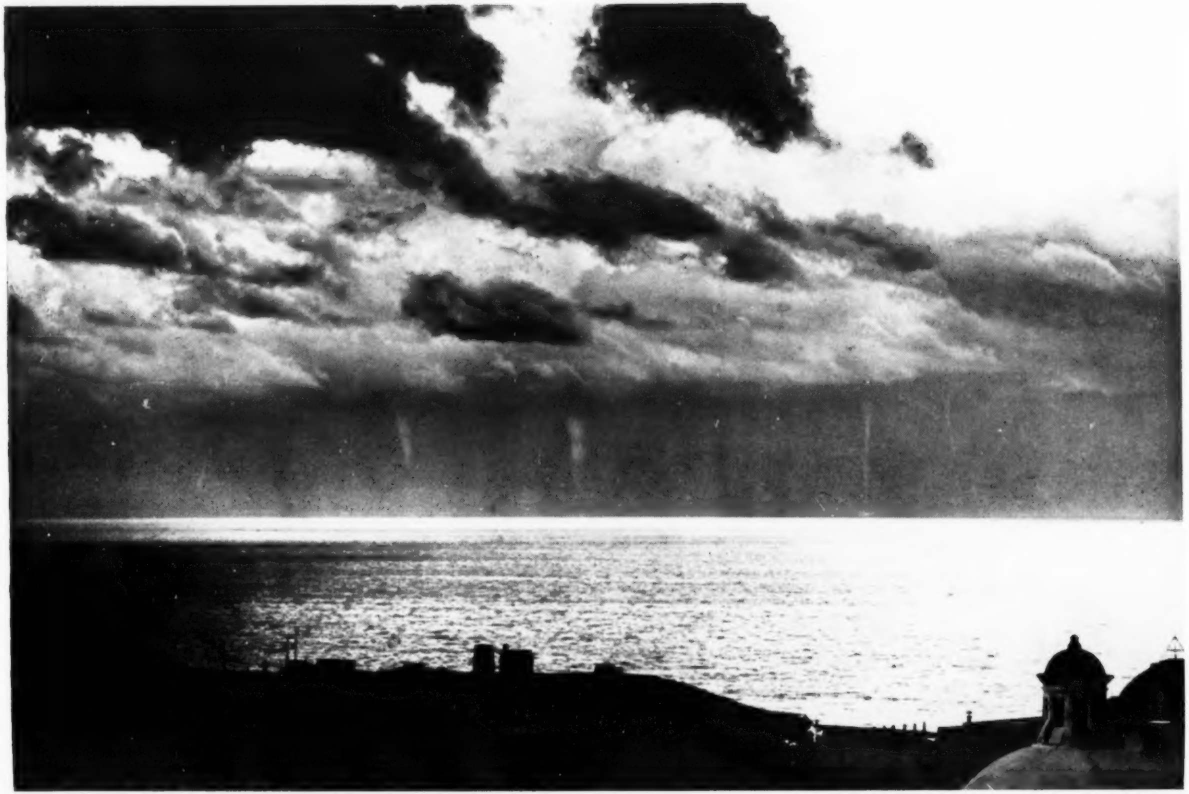
SUDDEN DISTURBANCE IN GLORIOUSLY FINE WEATHER

Photograph of rapidly moving cirrus seen from Col Chercrouit, just south of Mont Blanc, at 2.30 p.m., September 1, 1951. The summit of Mont Blanc and the Brouillard Ridge can be seen.

(see p. 91)



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WATERSPOUTS AT MALTA, 5.0 P.M., OCTOBER 14, 1930

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WATERSPOUTS AT MALTA, 5.45 P.M., OCTOBER 14, 1930

(see p. 91)

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EXAMINING OLD LOGBOOKS

Left to right: Capt. Pilcher, Capt. Fitzgerald, Sir Nelson Johnson, Capt. Whittle

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LUNCHEON PARTY AT THE METEOROLOGICAL OFFICE, HARROW

PRESENTATION OF BAROGRAPHS TO SHIPS' CAPTAINS

(See p. 89)

took long to compile. In practice, time was all important. If an observation of wind were given as a forecast for a later time there was a sharp increase in the error of the forecast in the first six hours or so; after about 30 hr. an observation is so stale that it is less accurate as a forecast than the normal wind of the season. He emphasized that the error in a route forecast was less than that at a point, the longer the route the less the error.

If the stretch vector correlation coefficient (r_{12}) is defined as

$$\frac{\Sigma\, |\mathbf{V}_1|\, |\mathbf{V}_2|\, \cos\theta_{12}}{\{\Sigma\, (\mathbf{V}_1^2)\, \Sigma\, (\mathbf{V}_2^2)\}^{\frac{1}{2}}}$$

where $\mathbf{V}_1$, $\mathbf{V}_2$ are the departures from normal of two series of vectors and θ_{12} is the angle between them, then it is possible to write a vector regression equation of $\mathbf{V}_1$ on, say, $\mathbf{V}_2$ and $\mathbf{V}_3$ in the form:—

$$\mathbf{V}_1 = a \left\{\frac{\Sigma\, (\mathbf{V}_1^2)}{\Sigma\, (\mathbf{V}_2^2)}\right\}^{\frac{1}{2}} \mathbf{V}_2 + b \left\{\frac{\Sigma\, (\mathbf{V}_1^2)}{\Sigma\, (c^2\, \mathbf{V}_3^2)}\right\}^{\frac{1}{2}} (c\, \mathbf{V}_3)$$

Suppose the series $\mathbf{V}_2$ represents winds at a certain time and a certain place, $\mathbf{V}_3$ represents winds at the same time but at a different place and with a weighting factor c appropriate to a circulation index; and suppose $\mathbf{V}_1$ represents wind at the same place as $\mathbf{V}_2$ but at a later time. Then a and b are functions of the partial correlation coefficients between $\mathbf{V}_1$, $\mathbf{V}_2$ and $(c\mathbf{V}_3)$. The regression equation can be used as a means of making a forecast of the wind $\mathbf{V}_1$.

As an example, the values of a and b had been determined from 120 observations made in the months June and July 1948 using winds at Downham Market and Aldergrove at 300 mb. Then, with the help of the resulting equation, forecasts had been made for 24 hr. ahead from observations made in July 1951. A table of errors was exhibited in which these forecasts were compared with those made by prontours, and it was seen that there was little to choose in accuracy between the two methods. Moreover if the two methods were suitably combined by a further regression equation the result showed an improvement of 5 or 10 per cent. on either.

Mr. Durst then showed some charts of stream lines and isotachs (lines of equal speed) drawn for the 300-mb. level which he claimed would avoid some of the principal errors referred to by Mr. Murray, e.g. those under the heading (i), (ii) and (vi). He showed also an isotach chart derived from prontours and for comparison an isotach chart drawn for the same date from statistical forecasts. The latter appeared to be much inferior to the former since the stronger winds were damped down, but when measurements were made at a number of points scattered over the charts it was found that the mean errors were much the same for both charts.

Mr. Durst then went on to give a comparison of the errors in 24-hr. route forecasts from Aldergrove to Berlin, a route selected as giving the greatest cover of accurate observations. The height chosen was 200 mb.; the statistical coefficients were calculated for the season December 1950 to February 1951; and the test was made over the month June 1951. The resulting errors are shown in the table below.

From the combination of prontour values and those derived from the regression equation the maximum error was $17\frac{1}{2}$ kt.

FREQUENCY OF ERRORS IN 24-HR. FORECASTS OF HEADWIND (OR TAILWIND) COMPONENTS FOR A ROUTE ALDERGROVE TO BERLIN AT THE 200-MB. LEVEL, JUNE 1951

	Error less than					
	5 kt.	10 kt.	15 kt.	20 kt.	25 kt.	>25 kt.
			occasions			
By prontours	15	21	27	29	30	0
By regression equation ...	13	20	24	26	29	1
By the mean of the two methods	14	22	28	30	30	0

Mr. Durst finally mentioned that the technique used in operations of the Comet aircraft was an initial fast climb to 25,000 or 35,000 ft., followed by a slow climb of 5,000 ft. in perhaps 1,000 to 1,200 miles, followed by a steep dive to the terminal airfield. To make forecasts for the various legs of such flights it might prove much simpler and more accurate to devise systems of regression equations than to attempt to interpolate values from charts.

Mr. Briggs summarized the methods at present used by the Forecasting Division, Dunstable. Contour and prontour charts are drawn by a building-up process: adding the "thickness" of each successive layer. Slides were shown to illustrate the marked continuity of thickness pattern at 300 and 100 mb. compared with the poor continuity at 200 mb. The number of observations which reach 100 mb. and can be accepted by the analyst are few, for errors in the basic pressure and temperature observations become very large at 200 and 100 mb. Also wind observations are exceedingly scarce so that the analyst is forced to accept a smoothing process to make the best use of all the observations, both of wind and temperature.

Prontours are deduced from the contours by a technique which is basically one of thickness-pattern extrapolation with a building-up process which starts from the surface prebaratic. In this whole process correspondence of high-level and low-level thickness patterns is maintained in the absence of any expected big development; general synoptic ideas are used, such as keeping the warm pools at 100 mb. in step with the cold troughs at 300 mb.

Winds are deduced directly from the prontours by use of a geostrophic scale. Results obtained during 1951 showed a 70 per cent. success in forecasting the 24-hr. wind variance at 300 mb. over Larkhill. In interpreting such results the effect of strong gradients must be remembered. A good prontour may still show large vector errors in such cases if the forecast and actual winds for a fixed time and place are compared. Geostrophic-scale measurement from a prontour really gives a mean wind for a distance of the order of 200 miles. Also prontours are really forecast flow patterns so that it is doubtful if a system of point checks can indicate the true value of prontours. For the period October–December 1951 results at 200 and 100 mb. showed, respectively, 77 per cent. and 66 per cent. success in forecasting the 24-hr. variance of the mean wind over the route London–Prestwick.

Statistical forecasts had the advantage of not requiring a prontour chart, but work had, practically, to be re-done for each and every route. They were severely limited by the observations available, and, at 100 mb., a statistical forecast would often amount to giving the seasonal mean wind; a wind which, at this level, is itself a very doubtful factor.

Mr. Cummings mentioned the difficulties in forecasting high-level winds for Comet aircraft on the route London to Rome due to the sparse network of observations over the Continent and the Mediterranean. He thought that the accuracy of mean-wind forecasts for east-west routes is likely to be higher than for north-south routes because of the normal west-to-east movement of irregularities of the flow pattern. Mr. Durst, in reply to Mr. Cummings, said that his statistics showed that there is little difference in accuracy between east-west and north-south forecasts of mean wind.

Mr. G. J. W. Oddie showed slides of the 200-mb. charts for 0300 G.M.T., July 9, 1951, constructed at the Central Forecasting Office and at Rome. The two charts were in good agreement near the British Isles but seriously different in the Mediterranean, mainly because the accuracy of the Malta, Tripoli and Benghazi observations was assessed differently by the two meteorological services. He thought that the regression-equation technique avoided really large errors; the prontour method aims at precision but when unsuccessful may introduce extreme errors. In practice it may be desirable to make sure of avoiding excessively large errors rather than attempting to produce correct forecasts.

Mr. Gold pointed out that the statistical method reduces major errors. He asked what period of the year had been examined by Mr. Murray? Also, whether it is possible in deducing winds from prontours to allow for differences between wind and geostrophic wind already in existence on contour charts? Mr. Murray replied that his data were based on April 1950. He did not think that, at the present time, it was possible to allow for pre-existing ageostrophic components in 24-hr. forecast charts—work by Neiburger and others in recent years suggests that the geostrophic approximation can scarcely be improved upon in practice.

Mr. Sawyer pointed out that Mr. Briggs, in checking the accuracy of forecast mean winds over a route at 100 mb., had not made any allowance for the inherent chart errors, so that the real forecasting errors at 100 mb. are likely to be less than he suggested. However, Mr. Sawyer mentioned that there is a good deal of persistence in the wind flow at 100 mb. In constructing 100-mb. contours wind observations 6 hr. or even 12 hr. old could often be used when current observations were not available.

Mr. Zobel said that, at Bawtry, 200-mb. prontours were constructed by gridding the surface prebaratic to the forecast 1000–200-mb. thickness. A test had shown that this method produced a root-mean-square 24-hr. forecast error of about 26 kt. He also mentioned that the apparent geostrophic departure on 200-mb. contour charts had been worked out, and it agreed with the value put forward by Mr. Murray. Comparison of 24-hr. wind forecasts by prontours and by Mr. Durst's simple regression equations showed that the prontour results were more accurate. However, the time required to prepare prontours was very considerable—a 24-hr. prontour was effective for only 12 hr. or so. The statistical technique enabled a 12-hr. forecast to be prepared quickly and simply from the latest wind observation. He also mentioned that the prontours received at outstations contained additional coding and transmission errors.

Miss Carruthers remarked on the rather flat 300–200-mb. thickness patterns shown by Mr. Briggs. She pointed out that the standard deviation of temperature varies with height; it is smallest between 300 and 250 mb. and has a

maximum at 170 mb. with a secondary maximum at 500 mb. Miss Carruthers asked Mr. Durst whether the regression equation took account of direction as well as speed. Mr. Durst stated that a vector regression equation did take account of direction, and illustrated on the blackboard how a vector regression equation could be solved graphically in a very short space of time.

Mr. Harley mentioned that flight routes over the Continent from London Airport were fixed, and the pilot of a Comet aircraft was not therefore interested in planning variations in routes according to the wind. He considered that the main cause of the long time required to complete contour charts was the delay in receiving the data and not the actual construction and analysis of the charts.

Mr. J. L. Galloway commented that jet-aircraft flights are of quite short duration, so that the main requirement is to have available really up-to-date wind observations from a few points along the route rather than long-period wind forecasts.

Mr. Holgate said that at Preston he was mainly concerned with short-period wind forecasts for the British Isles. For that purpose the longer-period prontours issued by the Central Forecasting Office were inferior to straightforward extrapolation of the wind field from more recent observations.

Mr. Kirk believed that a large part of the error associated with the prontours was due to errors in the prebaratic. Mr. Murray, in reply to Mr. Kirk, mentioned that, at least at the Central Forecasting Office, the prebaratic chart was not constructed independently of the upper air situation; prebaratic and prontour charts were closely inter-related.

Mr. Buchanan emphasized the collaboration between surface and upper air forecasters in the preparation of both prebaratic and prontour charts. It was of some interest that, after the high-level transatlantic flight of Canberra aircraft last winter, one of the pilots had written to the Central Forecasting Office and had congratulated the upper air analysts on the extremely accurate wind forecasts. However, Mr. Buchanan pleaded for more numerous and more accurate radio-sonde observations, especially in the regions away from the British Isles. He thought that the results of the Payerne trials were difficult to interpret.

Mr. Knighting said that, in ballistics, accurate point forecasts were essential—vector errors of 20–30 kt. were very serious. He considered that much of the apparent definiteness in the pattern of the 200–100-mb. thickness, mentioned by Mr. Briggs, might be illusory owing to the subjective element in constructing 100-mb. charts from such scanty information.

Dr. Harrison stated that the Payerne trials showed the characteristic differences between different types of radio-sondes used by different countries; it was difficult to say which sondes were most accurate. All flights at Payerne were carried out by highly trained personnel not working against time. The accuracy attainable at Payerne might not be reproduced in routine soundings if the organization and training of computers were not up to standard.

Mr. Taylor commented on the performance of British soundings. A test over the past 12 months had shown that wind observations at 100 mb. were obtained on about 45 per cent. of occasions. However, he thought that there was room for improvement in the quality of the balloons used.

The Director, in concluding the discussion, said that the charting and forecasting of very high-level winds was more or less a new problem. The contour chart and statistical method of wind forecasting could develop side by side. In the tropics, charts of mean values and departures of various elements were usually displayed in meteorological offices as a guide and warning to forecasters. He thought that the fine British network of upper air observing stations was a tribute to the planning of six or more years ago, when the need for winds at high levels had been foreseen. At present a new radio-sonde is under development.

METEOROLOGICAL RESEARCH COMMITTEE

The 62nd meeting of the main Meteorological Research Committee was held on November 29. The Committee reviewed the progress made during the past six months. The need for fast, high-flying aircraft for meteorological research was discussed, but it seems unlikely that such an aircraft will be obtained in the near future.

The Committee also considered various staffing matters in the Meteorological Office.

The 18th meeting of the Physical Sub-Committee of the Meteorological Research Committee was held on November 16, 1951. Two papers on visibility statistics were considered, one by Mr. Corby[1] dealing with visibility characteristics of Northolt Airport, and another by Dr. Goldie[2] discussing visibility statistics in general.

Mr. Durst presented a paper[3] dealing with the diurnal and seasonal height of pressure contours and Dr. Goldie read a related paper[4] on the subject of diurnal changes at high levels. Another aspect of the meteorology of the upper levels of the atmosphere was discussed in a paper by Mr. Bannon[5] who has examined the weather systems associated with occasions of severe turbulence at high altitude.

The Committee also discussed the possibility of examining atmospheric turbulence by means of smoke trails laid from aircraft, the variation with pressure of the velocity of sound in gases and some aspects of ice accretion on aircraft.

The 18th meeting of the Synoptic and Dynamical Sub-Committee was held on December 13, 1951. The Committee considered papers by Mr. Bushby on Charney's two-dimensional method of forecasting the instantaneous height tendency[6] and on the computation of the field of mean vertical velocity in the 1000–500-mb. layer of the atmosphere and its effect on the thickness of the layer[7].

A paper by Mr. W. E. Saunders on some further aspects of night cooling under clear skies aroused much interest[8].

Other matters discussed included (*a*) a comparison between rainfall amounts and Sutcliffe's expression for cyclonic development and (*b*) the question of the variability of the winds at 200 mb. in April 1950 at Larkhill.

[1] *Met. Res. Pap., London,* No. 680, 1951
[2] *Met. Res. Pap., London,* No. 691, 1951
[3] *Met. Res. Pap., London,* No. 675, 1951
[4] *Met. Res. Pap., London,* No. 684, 1951
[5] *Met. Res. Pap., London,* No. 669, 1951
[6] *Met. Res. Pap., London,* No. 670, 1951
[7] *Met. Res. Pap., London,* No. 682, 1951
[8] *Met. Res. Pap., London,* No. 687, 1951

OFFICIAL PUBLICATION

The following publication has recently been issued:—

METEOROLOGICAL REPORTS.

No. 10—Memorandum on the intertropical front. Compiled by J. S. Sawyer, M.A.

The area of disturbed weather which separates the wind systems of the northern and southern hemisphere has come to be known as the intertropical front. A considerable increase in knowledge about it was derived from the war-time meteorological organization in the equatorial regions. The present report summarizes the experience then gained for the guidance of both weather forecasters and airmen. The characteristics of the intertropical front are described both as regards oceanic areas where it separates the two trade-wind systems and the continental areas where it forms the limit of a monsoon current.

ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society held on January 16, the President, Sir Charles Normand, in the Chair, the following papers were read:—

*Riehl, H., Yeh, T. C., Malkus, J. S., and La Seur, N.E.—The north-east trade of the Pacific Ocean**

Dr. Malkus read the paper written by herself, H. Riehl, T. C. Yeh and N. E. La Seur. In the summer of 1945 three weather ships of the U.S. Navy were stationed north-east of Hawaii, and this, with the station at Honolulu, gave four observing stations very closely along the summer direction of the trade-winds over a distance of 1,500 miles. The weather ships made radio-sonde and pilot-balloon observations as well as surface observations. The data used in the paper were for the months July to October 1945. From these data were calculated vertical cross-sections along the trades, up to a pressure of 700 mb., of wind steadiness, wind speed, temperature and specific and relative humidity.

The vertical structure of the trades was found to be: (*a*) a layer of nearly dry-adiabatic lapse rate from the surface up to the base of the trade-wind cumuli which was at about 950 mb. at the north-east point and 930 mb. at Honolulu, (*b*) cloud layer of lapse rate approximating to the saturated adiabatic but decreasing upwards, and (*c*) a nearly isothermal region, the "trade-wind inversion", of base at about 900 mb. at the north-east point and 800 mb. at Honolulu, and top about 800 mb. at the north-east end and probably at 750 mb. at Honolulu. The wind speed increased upwards to a maximum about 900 mb. and then decreased. The magnitude of the descending air current was calculated from the divergence, and found to be of the order of 195 ft. a day at 700 to 800 mb., so that in the 6 days taken by the air to cover the distance considered the upper air sinks about 1,200 ft. Such a rate of sinking means that the air does not remain throughout in one of the main structural layers. The base of the inversion rises along the wind in spite of the descending air motion because moisture is carried upwards by the cumulus clouds which penetrate into the inversion layer and gradually transform it. The upward fluxes of latent heat and sensible heat from the sea surface were computed, and show that a net amount of latent heat is carried away from the area and is available to balance radiation losses elsewhere. The momentum

Quart. J. R. met. Soc., London, **77**, 1951, p. 598.

transfer is also computed, and is naturally upwards near the ground but downwards higher up where the wind speed decreases with height so that the trade winds receive westerly momentum from both above and below. Comparison of the intensity of the vertical fluxes of momentum and water vapour showed that the coefficient of turbulent exchange of momentum increased upward, and the corresponding quantity for water vapour decreased upwards at least to the inversion layer; and the ratio of the former to the latter was large above the cloud layer.

In the course of the discussion Dr. Crowe pointed out that the area considered in the paper was the northern half of the trades, and it would be interesting to see what happens further south where further downward motion had taken place. Mr. Bonacina said he had concluded from the very heavy rainfall on the Hawaiian mountains that there must be great instability in the lower levels, and this was confirmed in the paper which showed instability to above the mountain tops. Prof. Sheppard was particularly interested in the vertical flux of momentum which did not conform at all to the conventional ideas of a frictional layer at the base above which there was very little or no friction. Dr. Forsdyke pointed out that the not negligible rainfall in the area, over 1 in. a month, could hardly be considered as coming from the trade-wind cumuli extending only to 700 mb. where temperature was about 50°F.

*Scorer, R. S.—Mountain-gap winds; a study of surface wind at Gibraltar**

The surface wind in the Straits of Gibraltar discussed by Dr. Scorer provides a very interesting field of application of dynamical meteorology.

There is a marked difference between the flow when the lower air is stable and when convection is active. The former flow is the more interesting as the surface wind when convection is active follows the upper wind without any very remarkable features.

When the lower air is stable the flow through the Straits is towards the end where surface pressure is lowest and may depart very greatly from the upper wind. Because of the venturi-like topography the wind is very strong in comparison with that over the sea outside the Straits. Winds of 100 kt. have been observed in the Straits at heights of 100 to 400 ft. when the general wind above the mountains was only 20 to 30 kt. Observations made by aircraft show the air converging towards the Straits does so steadily, but the emerging air blows for a long way in a narrow jet bounded by eddies and does not tend much to spread sideways. On occasions when a shallow pool of cold air is spreading slowly southwards over the area the wind will blow through the Straits towards the side where the lower layers are warmer. On other occasions when there is no marked difference in air mass between the two ends the surface wind will be across the isobars into low pressure. Small changes in pressure gradient may then lead to large changes in surface wind. Even the small gradients associated with the semi-diurnal pressure wave seem to be important. Local katabatic winds also complicate the picture when the general winds are light.

A particularly interesting occurrence is the inversion of the normal diurnal variation of wind velocity which often occurs when a strong easterly wind blows from a shallow cold pool in the Mediterranean. The lowest layers are then in roughly neutral equilibrium but above these there is a very stable layer. If

*Quart. J. R. met. Soc., London, 78, 1952, p. 53.

the low-level wind decreases with height, as it may on account of the funnel effect, the increased stability of the lower layers at night means that the surface air will then lose less momentum upwards so that its speed increases.

There was no time for discussion of Dr. Scorer's paper.

LETTER TO THE EDITOR

Triple-walled waterspout

An interesting waterspout was observed from start to finish from the S.S. *Empire Fowey* in the South China Sea at approximately 3°30′N., 106°E. at 0730 G.M.T. (1500 Malayan Standard Time) on May 27, 1951.

It began as a faint tube of cloud particles emerging from a cumulus base estimated to be slightly above 2,000 ft. Directly underneath, the sea was disturbed and throwing up spray to about 100 ft. in a circular area 300 ft. wide. In the second stage the tube, which appeared to be hollow, extended downwards to meet the surface spray. In its third stage, the tube which was about

30 ft. in diameter, apparently formed a second hollow cloud tube inside the first tube for about the middle third of its length. In the fourth stage, a thick cloud sleeve about 400 ft. long and 150 ft. wide grew downwards from the cloud base concealing the original spout and a similar sleeve or annulus grew from the sea at the same time. The spray from the sea surface remained visible outside the sleeve. The reverse processes now took place, and when the spout had reached the second stage again a shower spread from the north, enveloped it and hastened its decay, although it was possible to discern foam on the sea surface five minutes after the spout was no longer visible. No rotation was observable at any time except in the spray which appeared to drift slowly in a clockwise direction.

Weather at the time was cloudy with 7 oktas of large cumulus and cumulonimbus. There were three slight showers to the north and three moderate

showers to the south. Surface wind was estimated to be S., 10 kt. Visibility was thirty miles and sea slight. An examination of synoptic charts on return to Changi showed that the area was affected by a south-easterly air stream flowing up the Java Sea and turning to southerly and then south-westerly in the South China Sea north of the equator. There was a convergence zone running east-west about 200 miles to the north of the ship's position and the intertropical front was still further north over French Indo-China. Thus there was nothing abnormal at the time; in fact, waterspouts are a fairly common occurrence in this region.

The spout was very near to where the ship had just passed, and was estimated to be originally three or four miles away, the whole incident lasting twenty minutes while the ship was doing 16 kt.; possibly the spout was initiated by an air eddy set up by the motion of the ship.

P. E. PHILLIPS

Changi, August 23, 1951

NOTES AND NEWS

Maritime occasion at Harrow

A recent ceremony held in the Meteorological Office at Harrow centred around the presentation of suitably inscribed barographs to four Merchant Navy Captains whose long-standing association with the Meteorological Office typifies the invaluable voluntary work carried out at sea by ships of the British "selected" fleet.

Captain Fitzgerald of the Cunard Company's *Vardulia*, Captain Pilcher of the New Zealand Shipping Company's *Haparangi*, and Captain Whittle of the Royal Mail Lines' *Asturias*, were the recipients for the award on November 27. Captains Wood, Anderson and Spriddell, the marine superintendents of the companies concerned were also present. Captain Eckford of the Pacific Steam Navigation Company's *Cuzco*, was at sea at the time, and the presentation to him has since been made at Liverpool on his ship's return there.

Sir Nelson Johnson, in making the presentations, emphasized the importance of maritime observations to meteorological services of the world, both for synoptic and climatological purposes. He said that the ocean weather ships received a good deal of publicity, but the masters and officers of merchant ships, who do such useful meteorological work at sea in all oceans, did not get the same limelight. He was glad to have the opportunity of publicly thanking all voluntary observers in "selected" ships and indeed the entire shipping industry for the fine spirit of co-operation which enabled this vital work to be carried out.

Sir Nelson spoke of the long connexions with the Meteorological Office of each of the three shipping companies represented—connexions dating back to the founding of the Meteorological Office under Admiral Fitzroy nearly a hundred years ago. Before presenting the barographs, he gave some details about the quality of the work done by Captains Fitzgerald, Pilcher and Whittle, during, in each case, more than 15 years of observing and recording the weather at sea.

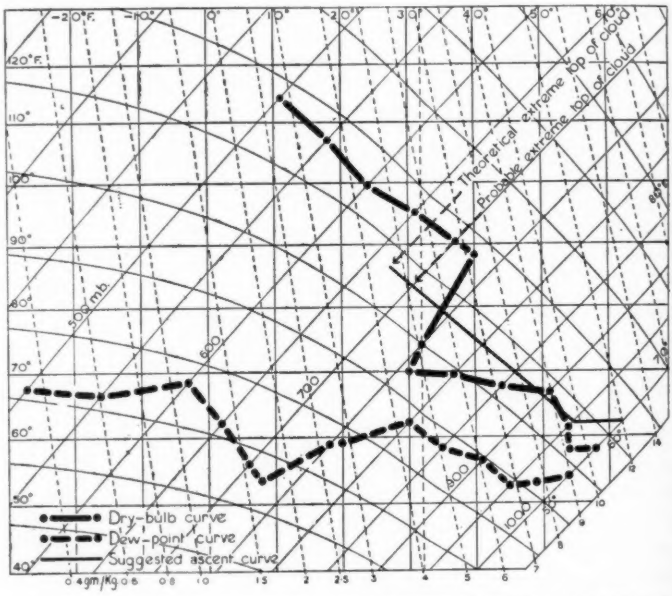
The presentations followed a luncheon given in the Meteorological Office building at Harrow, which was also attended by Captain Macky Senior Warden, Captain Fisher a Member and Mr. Smith the Clerk of the Honourable Company of Master Mariners, who have been closely associated with such

presentations on previous occasions. Captain Quick, the Principal Examiner of Masters and Mates, who is a member of the Meteorological Committee, was also present, together with some senior members of the Meteorological Office Staff. After luncheon the guests had the opportunity of inspecting the work of the Marine Branch.

Unexpected heavy rain

On October 3, 1951, when mainly dry weather was expected, rain or drizzle was reported from several places in south-west England and south Wales. Falls were mostly small in amount, but, in the Plymouth area, heavy rain fell during the late afternoon, 0·28 in. being recorded at Mount Batten between 1530 and 1715 G.M.T.

Anticyclones were centred north-east of the Azores and over Scandinavia with a strong connecting ridge across the British Isles. Over south-west England there was a pressure gradient for light E.–NE. winds and no evidence of any fronts. A study of the situation suggests that the radio-sonde ascent made at Camborne at 1500 G.M.T. gave a broadly correct indication of the temperature distribution over Plymouth at the time the rain fell.



TEPHIGRAM OF RADIO-SONDE ASCENT OVER CAMBORNE, CORNWALL, AT 1500 G.M.T., OCTOBER 3, 1951

Cumuliform cloud was not observed at Mount Batten nor was any reported from neighbouring stations, but, with surface temperature and dew point of 62°F. and 58°F. respectively at Mount Batten during the afternoon, isolated cumulus clouds could have been produced with a wet-bulb potential temperature in the cloud column of about 58°F. Observation and theory indicate that convection clouds may penetrate some distance into an inversion layer. Using

the "parcel method" convection may theoretically continue until the "positive" and "negative" areas between the environment curve and the ascent curve on the tephigram are equal. On this occasion, ascent along the 58°F. wet-bulb potential-temperature line might have resulted in the cloud tops penetrating as high as 670 mb. This is the extreme, however, and, allowing for frictional and other damping effects, it is unlikely that the tops reached above 700 mb., at which height the cloud would have had a temperature of 30°F.

The base of the cloud when the rain commenced was 2,000 ft. Heavy rain therefore fell from a cloud of thickness about 8,000 ft. of which only the top 600 ft. or thereabouts could have been at a temperature below freezing point.

Acknowledgement is made to Mr. C. K. M. Douglas for some valuable comments which have been incorporated in this note.

P. F. ILLSLEY

Waterspouts at Malta, October 14, 1930

The waterspouts at Malta illustrated in the centre of this magazine occurred on a cold front which moved slowly south-eastwards across the west and central Mediterranean Sea. The fresh polar air behind the front became very unstable as it moved south-eastwards over the warm sea. The front was associated with a shallow secondary depression, the last of a family, which formed between the Azores and Spain on October 10, and moved steadily towards the Black Sea where it almost completely filled up on the 14th.

The waterspouts were visible to the north and south of the meteorological office at Valetta from 1525 until dark. There were lightning and thunder to the north-east; and again more lightning and thunder between 1900 and 2000. The waterspouts were a remarkable sight, as many as ten being seen at the same time, like so many pillars against a dark background supporting a canopy of yellow, orange and red clouds as the sun began to set.

Cirrus over Mont Blanc

The photograph facing p. 80 was taken by Mr. H. A. Meyer, of the Ministry of Civil Aviation, at 2.30 p.m. on September 1, 1951, from the Col Checrouit looking a little east of north towards Mont Blanc, the summit of which is seen with the Brouillard Ridge.

The fibrous cirrus cloud appeared very suddenly in fine weather and moved at a high speed. It appears to have formed on the upper part of a warm front which at the time extended south-east across France from a small depression whose centre moved along the English Channel during the day. The cloud of this depression blotted out, over most of northern France and southern England, the view of the partial eclipse of the sun which took place on that afternoon.

Obituary Notice of Professor V. F. K. Bjerknes, For.Mem.R.S., by E. Gold, F.R.S.

Mr. Gold has written for the *Obituary Notices of Fellows of the Royal Society* the obituary of Professor V. F. K. Bjerknes.

The Notice is, apart from the interest attaching to the description of V. Bjerknes's own work and personality, a valuable contribution to the history of meteorology. Anyone who wishes to study the development of the application

of physics and mathematics to meteorology during the period from 1890 to 1945 would be well advised to begin by reading Mr. Gold's obituary notices of Sir Napier Shaw and Prof. V. F. K. Bjerknes*.

Copies of both Notices are available in the Meteorological Office Library (M.O.20) and in the Technical Libraries of the Special Investigations Branch (M.O.9) and Forecasting Research Branch (M.O.22).

OBITUARY

Edward John Percival, B.A.—It was with deep regret that we learnt of the death of E. J. Percival on November 1, 1951, at the early age of 40 years, following his short, but, often painful, illness—cheerfully borne.

After a brilliant career at Jesus College, Cambridge, during which he obtained 1st class Honours in Parts I and II of the Mathematical Tripos he was engaged by a firm of scientific consultants and remained with them until joining the Meteorological Office as a Forecaster, Grade II, soon after the outbreak of the Second World War 1939–1945. He served in west Africa and in England. Although many war-time entrants to the Meteorological Office returned to their former occupations with their release from the R.A.F.V.R. Percival had become intrigued by the subject of meteorology and expressed a wish to remain in the Office. In consequence, he was appointed Senior Scientific Officer from January 1, 1946.

His special interest was synoptic meteorology although he was well qualified and sufficiently gifted to have undertaken work in, and make contributions to, almost any branch of the science. In June 1942, when in west Africa, he had the vision to see how radar could be used in upper wind observing, and he was the first to organize observations by this means with the co-operation of the Army authorities. His last task, before being stricken by his fatal illness, was a valuable contribution in the field of synoptic climatology.

Percival was able to hide his preoccupations and worries and thus appeared to be always cheerful and bright no matter what difficulties beset him; he retained these qualities even when he must have known that his illness was to prove fatal. He had the capacity to make friends easily and quickly and was very popular in R.A.F. Messes; many of these friendships made by himself and his wife were of an enduring nature, so that when the final blow came Mrs. Percival received a great deal of sympathy, comfort and practical help when she needed it so dearly.

Although he was a man of many interests, Percival did not lean towards sports such as football or cricket. He was, however, a keen equestrian and he and his wife were members of the B.A.F.O. Riding Club during their stay in Germany. As might be expected, Percival was interested in both bridge and chess and was no mean performer of these games which require special mental gifts in order to play them really well. One of his daily recreations which he always enjoyed was to try to complete *The Times* crossword, during the lunch break, in the shortest time possible.

Although his physical deterioration was so awfully apparent to his relatives and friends, he remained until the end alert in mind and managed to continue reading until the last few days. Only ten days before his death he said how

* *Obit. Not. Fellows roy. Soc., London*, **5**, 1945, p. 203, and **7**, 1951, p. 303.

anxious he was to resume and complete the work he had begun at Headquarters, Bomber Command.

The Meteorological Office has lost a gifted and good companion, and our very deep sympathy is extended to Mrs. Eileen Percival and her son Andrew in their grievous loss.

BOOK RECEIVED

Indian Journal of Meteorology and Geophysics, **2**, 1951, No. 3, India Meteorological Department. $9\frac{1}{2}$ in. $\times$ $7\frac{1}{4}$ in., pp. ii+165–242. Manager of Publications, Delhi, 1951. Price: *Rs*. 2/8 or 4*s*.

ERRATUM

December 1951, PAGE 345, Fig. 3; The isopleth in the bottom right-hand corner should be labelled 5 and not 10.

METEOROLOGICAL OFFICE NEWS

Birmingham's water supply.—The film "Birmingham's water supply" kindly lent by the Birmingham Water Department, was shown at the Meteorological Office, Harrow, on January 23, 1952. Although the film contained only a passing reference to rainfall observing—there was a brief shot of an observer reading a gauge—the importance of rainfall recording to a water scheme was frequently implied. It brought added meaning to the work of the hydrological and rainfall sections of the Office.

Training course for crop weather observers.—Twenty-one observers from crop weather stations attended a course of lectures in meteorology and in observational and recording technique given at the Meteorological Office Training School, from November 19 to November 22. The observers visited the Climatology and Instrument Divisions of the Office at Harrow on November 23 and saw something of the application of their records to agricultural meteorology. The observers expressed appreciation of the lectures and of the thorough way in which light had been thrown on their meteorological work. They made suggestions for future lectures, including more advanced work. The next course, which will be adapted to suit observers from both crop weather and health resort stations, is planned for October 1952.

Ocean weather ships.—O.W.S. *Weather Observer* spent Christmas on station JIG. Mail and parcels, including a large Christmas tree, the gift of the R.A.F. Kinloss, were dropped by an aircraft of R.A.F. Coastal Command. It had been hoped to obtain some interesting photographs of the arrival of the mail, but a very heavy swell and moderate SW. gale precluded boat work and a grappling iron had to be used instead for retrieving it. Messages of seasonal greetings and thanks were exchanged by the aircraft and the ship.

The weather on Christmas Day was not so bad as to preclude enjoyment of Christmas dinner and a party, but on December 26 the barometer fell steeply. In four hours (1800 to 2200) the wind increased from force 6 to a force greater than force 12. In this hour the sea, which was ordinarily rough, became a boiling mass of white with continuous driving spray at mast height.

Commenting upon the voyage in general, Captain Israel, Master of the *Weather Observer*, from whose report the above condensed notes have been made, writes:

"The whole voyage has been one of excessive bad weather . . . The storms of the 26th/27th December were the worst I have seen in the North Atlantic

and simulated a compact West Indian hurricane . . . Always having a great deal of faith in Corvettes, I have never before had the chance of this supreme test for one. They are without doubt the finest sea ships in commission and their fortunate length (which fits between waves) has a great deal to do with it. One cannot help but mark that within three hundred miles 10,000-ton cargo steamers were in trouble, one being the famous *Flying Enterprise*."

In view of the extraordinarily severe weather on this voyage, the continuous maintenance of the meteorological routine reflects great credit on all staff concerned.

Transfer of staff to Colonial Meteorological Services.—Two more Assistants left in January for the Colonies, Mr. D. R. Walker to Nyasaland and Mr. V. J. Wooller to Bermuda.

Social and sporting activites.—The Meteorological Office, Croydon, held an enjoyable party on January 11, when some past members of the staff joined other present members and their friends for a social evening which concluded with a visit to "King's Rhapsody". Staff who have served at the Meteorological Office, Croydon, and who are interested in any similar gatherings in the future are invited to forward their names and addresses to that office.

Miss B. Edwards, of M.O.20 (Editing), Harrow, played for the Civil Service in a netball match against the Women's Royal Air Force team on January 14. The Civil Service team won by 11 goals to 8.

WEATHER OF JANUARY 1952

Mean pressure was abnormally low off the west coast of Norway, falling below 1000 mb. and as low as 994 mb. in places. Over Scandinavia generally mean pressure was 5–10 mb. below normal. Low mean pressure extended also over Europe and the Mediterranean; it was 1005 mb. in Denmark, nearly 10 mb. below normal, increasing to 1015 mb. in the Mediterranean, about 2 or 3 mb. below normal. Mean pressure in the North Atlantic was high, with the Azores anticyclone well established. Mean pressure was about 1008 mb. in latitude 55°N., 5 mb. above normal, and increased to 1030 mb. in the Azores, which was about 10 mb. above normal.

Mean temperature was 15–30°F. in Scandinavia, 30–40°F. in Europe and 50°F. in the Mediterranean. Departures from normal were generally small, being slightly above normal in Europe and below in the Mediterranean.

In the British Isles the weather was mainly sunny for the time of year with a very cold spell during the latter half of the month. Snow or sleet fell frequently and lay in some places in the west and north from the 16th or 17th onwards. A widespread gale occurred on the 15th, the wind reaching hurricane force in the Orkneys.

In the opening days a complex depression was situated over Scandinavia, while a secondary disturbance crossed the British Isles; rather cold W.-N. winds prevailed with wintry showers and long bright periods in the south and east on the 1st and 2nd and sunny spells over a wider area on the 3rd. On the 4th a trough of low pressure crossed the country giving precipitation generally, mainly in the form of rain. From the 4th to the 6th a very deep depression moved from mid Atlantic to the north-east of Greenland and a milder south-westerly air stream prevailed over the British Isles, with rain in the west and north and fog and slight drizzle in the south. Meanwhile pressure

became high in a belt from the Azores across France to Germany. On the 8th a deep depression over Iceland moved east and turned north-east, while an associated trough moved east over the British Isles causing general rain, but conditions continued mild. Colder westerly winds brought a fall in temperature on the 9th, with wintry showers, the snow being heavy locally in the north of Scotland; snow lay to a depth of 1 ft. at Dalwhinnie on the 10th. These colder conditions persisted in the north but a trough of low pressure, moving south-east across the southern half of the country, was associated with a temporary rise in temperature in this area, the 10th being the mildest day of the month in parts of England. Rainfall was heavy in some areas on the 9th and 10th (2·14 in. at Gam, Montgomeryshire, on the 10th). During the next few days rather cold, northerly winds prevailed, with showers and bright periods but on the 14th–15th a deep depression moved east-north-east along our northern seaboard and associated troughs moved south-east across the country. Temperature rose and widespread strong winds and gales occurred, the gale being very severe in the north of Scotland; hurricane force was reached in the Orkneys causing immense damage. Subsequently a depression moved from west of Iceland to Germany. Cold northerly or north-westerly winds prevailed, reaching gale force on the 17th and 18th; widespread snow occurred on the 17th and 18th. Thereafter a belt of high pressure lay across the British Isles joining anticyclones over Scandinavia and the Azores. Cold dry weather prevailed in most parts from the 19th to the 21st, with long sunny periods on the 19th and 20th. On the 22nd and 23rd a small disturbance moved from the Hebrides across Ireland to the Bay of Biscay. Temperature continued low and the weather was dull, with some precipitation. Subsequently pressure was low eastward of the British Isles and high to the westward and a spell of very cold weather ensued with widespread sleet or snow, though the snow cover was thin over a wide area in the south-east. Air temperature fell to 6°F. at Silloth and 2°F. at Shawbury on the 27th. On the 28th a trough of low pressure moved rather quickly north-east over the country and was followed by a ridge; more snow occurred on the 28th and temperature fell to 2°F. at Glentress that morning. In the closing days a deep trough moved east giving further precipitation. Snow lay locally on high ground in the west and north from the 16th or 17th until the end of the month; at Bwlchgwyn (1,267 ft.) in Denbighshire, for example, level snow lay 10 in. deep on the morning of the 27th and increased to 14 in. on the 31st, with drifts up to 4 ft. on the 27th. At Eskdalemuir air temperature remained continuously below 32°F. from the 22nd to the 28th inclusive.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	56	2	−2·2	113	+2	144
Scotland	55	2	−4·8	110	0	134
Northern Ireland ...	53	18	−4·1	147	+5	102

RAINFALL OF JANUARY 1952

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	1·64	88	*Glam.*	Cardiff, Penylan ...	3·26	[illegible]
Kent	Folkestone, Cherry Gdn.	3·22	143	*Pemb.*	Tenby	4·29	[illegible]
,,	Edenbridge, Falconhurst	2·88	118	*Mer.*	Aberdovey	3·78	97
Sussex	Compton, Compton Ho.	3·09	97	*Radnor*	Tyrmynydd	9·16	[illegible]
,,	Worthing, Beach Ho. Pk.	2·70	116	*Mont.*	Lake Vyrnwy	9·65	[illegible]
Hants.	Ventnor Cemetery ...	2·90	111	*Mer.*	Blaenau Festiniog ...	12·37	121
,,	Bournemouth	2·00	74	*Carn.*	Llandudno	3·40	[illegible]
,,	Sherborne St. John ...	2·40	103	*Angl.*	Llanerchymedd ...	4·39	[illegible]
Herts.	Royston, Therfield Rec.	1·44	83	*I. Man*	Douglas, Borough Cem.	3·80	[illegible]
Bucks.	Slough, Upton	1·80	97	*Wigtown*	Newton Stewart ...	4·49	[illegible]
Oxford	Oxford, Radcliffe ...	1·82	101	*Dumf.*	Dumfries, Crichton R.I.	3·90	[illegible]
N'hants.	Wellingboro' Swanspool	1·52	82	,,	Eskdalemuir Obsy. ...	7·61	[illegible]
Essex	Shoeburyness	1·48	110	*Roxb.*	Kelso, Floors	2·00	[illegible]
,,	Dovercourt	2·48	155	*Peebles*	Stobo Castle	4·56	[illegible]
Suffolk	Lowestoft Sec. School ...	2·52	151	*Berwick*	Marchmont House ...	1·86	[illegible]
,,	Bury St. Ed., Westley H.	2·47	138	*E. Loth.*	North Berwick Res. ...	0·88	[illegible]
Norfolk	Sandringham Ho. Gdns.	2·57	132	*Midl'n.*	Edinburgh, Blackf'd. H.	2·45	[illegible]
Wilts.	Aldbourne	2·68	116	*Lanark*	Hamilton W. W., T'nhill	3·60	[illegible]
Dorset	Creech Grange... ...	2·75	84	*Ayr*	Colmonell, Knockdolian	5·04	[illegible]
,,	Beaminster, East St. ...	3·34	96	,,	Glen Afton, Ayr San. ...	8·08	[illegible]
Devon	Teignmouth, Den Gdns.	3·11	107	*Renfrew.*	Greenock, Prospect Hill	7·75	[illegible]
,,	Cullompton	4·19	129	*Bute*	Rothesay, Ardencraig ...	5·66	[illegible]
,,	Ilfracombe	4·58	139	*Argyll*	Morven (Drimnin) ...	6·02	[illegible]
,,	Okehampton Uplands...	7·51	147	,,	Poltalloch	7·60	[illegible]
Cornwall	Bude, School House ...	3·40	112	,,	Inveraray Castle ...	8·83	[illegible]
,,	Penzance, Morrab Gdns.	6·10	161	,,	Islay, Eallabus	...	...
,,	St. Austell	5·46	128	,,	Tiree	5·27	[illegible]
,,	Scilly, Tresco Abbey ...	3·64	116	*Kinross*	Loch Leven Sluice ...	3·00	[illegible]
Glos.	Cirencester	2·21	88	*Fife*	Leuchars Airfield ...	0·94	[illegible]
Salop	Church Stretton ...	3·47	133	*Perth*	Loch Dhu	...	...
,,	Shrewsbury	2·43	125	,,	Crieff, Strathearn Hyd.	2·75	[illegible]
Worcs.	Malvern, Free Library...	2·22	100	,,	Pitlochry, Fincastle ...	3·35	[illegible]
Warwick	Birmingham, Edgbaston	2·72	135	*Angus*	Montrose, Sunnyside ...	1·34	[illegible]
Leics.	Thornton Reservoir ...	1·93	97	*Aberd.*	Braemar	2·73	[illegible]
Lincs.	Boston, Skirbeck ...	1·52	94	,,	Dyce, Craibstone ...	2·66	[illegible]
,,	Skegness, Marine Gdns.	1·57	91	,,	New Deer School House	3·67	[illegible]
Notts.	Mansfield, Carr Bank ...	1·80	84	*Moray*	Gordon Castle	2·93	[illegible]
Derby	Buxton, Terrace Slopes	6·61	148	*Nairn*	Nairn, Achareidh ...	1·73	[illegible]
Ches.	Bidston Observatory ...	2·64	125	*Inverness*	Loch Ness, Garthbeg ...	4·67	[illegible]
Lancs.	Manchester, Whit. Park	3·29	131	,,	Glenquoich	11·54	[illegible]
,,	Stonyhurst College ...	5·43	127	,,	Fort William, Teviot ...	7·79	[illegible]
,,	Squires Gate	2·82	108	,,	Skye, Duntuilm ...	5·63	[illegible]
Yorks.	Wakefield, Clarence Pk.	1·92	100	,,	Skye, Broadford ...	7·54	[illegible]
,,	Hull, Pearson Park ...	1·53	85	*R. & C.*	Tain, Tarlogie House ...	2·17	[illegible]
,,	Felixkirk, Mt. St. John...	1·73	87	,,	Inverbroom, Glackour...	9·77	[illegible]
,,	York Museum	1·58	89	,,	Achnashellach	8·67	[illegible]
,,	Scarborough	2·72	136	*Suth.*	Loch More, Achfary ...	7·54	[illegible]
,,	Middlesbrough... ...	1·62	101	*Caith.*	Wick Airfield	3·67	[illegible]
,,	Baldersdale, Hury Res.	3·14	97	*Shetland*	Lerwick Observatory ...	4·64	[illegible]
Norl'd.	Newcastle, Leazes Pk....	1·54	78	*Ferm.*	Crom Castle	4·35	[illegible]
,,	Bellingham, High Green	3·20	112	*Armagh*	Armagh Observatory ...	4·60	[illegible]
,,	Lilburn Tower Gdns. ...	2·59	125	*Down*	Seaforde	3·44	[illegible]
Cumb.	Geltsdale	3·77	135	*Antrim*	Aldergrove Airfield ...	3·10	[illegible]
,,	Keswick, High Hill ...	5·79	115	,,	Ballymena, Harryville...	4·89	[illegible]
,,	Ravenglass, The Grove	2·94	88	*L'derry*	Garvagh, Moneydig ...	6·57	[illegible]
Mon.	Abergavenny, Larchfield	3·67	109	,,	Londonderry, Creggan	6·10	[illegible]
Glam.	Ystalyfera, Wern House	8·48	134	*Tyrone*	Omagh, Edenfel ...	5·37	[illegible]